CONFIDENTIAL

AD 139544

Armed Services Technical Information Agency

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

FOR
MICRO-CARD
CONTROL ONLY

1 OF 1

CONFIDENTIAL

BEST

AVAILABLE

COPY

1395441

JEIA No. 11389

Communicated by Chief Superintendent/R.R.D.E. RESTRICTED

R.R.D.E. RESEARCH REPORT No.2[illegible]

THE INTENSITY OF COSMIC NOISE. A SURVEY OF THE DATA AVAILABLE

by J. M. C. Scott

SUMMARY

The sensitivity of Radar sets operating in the region 5 to 15 metres (20 - 60 megacycles) is determined primarily by aerial (i.e. Cosmic) noise and not by valve noise. This has a number of practical consequences: for example, there may be little advantage to be gained by improving the figure of merit of the receiver; or when a good receiver is used a certain amount of loss can be tolerated, for instance, in long aerial feeders, without causing a proportionate ill effect on overall performance.

The data available at present on the intensity of cosmic noise have been surveyed critically, with the object of estimating the absolute intensity of noise which may be expected with any actual equipment.

CONTENTS

1. General Characteristics of Cosmic Noise
2. Discussion of the Available Experimental Data:
   (A) Angular Distribution of Noise Sources over the Sky
3. Discussion of the Available Experimental Data:
   (B) Data on the Absolute Intensity
4. Comparison of Experimental Values at Different Frequencies
5. Final result

References
Addendum

Appendix: Radiation in an Enclosure in Thermodynamic Equilibrium. Application to Aerials

Diagrams

Fig. 1 Cosmic Noise vs Wavelength.

1. GENERAL CHARACTERISTICS OF COSMIC NOISE

It was discovered by Jansky in 1932, working on 2[illegible] that the aerial noise on that frequency shows a diurnal [illegible] both in its intensity and in its direction of arrival. [illegible] experiment showed that the periodicity was not quite [illegible] 23 hours 56 minutes, corresponding to the period of [illegible] rotation relative to the stars. The source of this [illegible] rather the pattern of sources, was thus shown to be [illegible] It is found that the noise comes principally from [illegible] and in particular the most "noisy" part of the Milky [illegible] to be that in the direction of the constellation [illegible] is known to be the direction of the centre [illegible]

An aerial which is in thermal equilibrium [illegible] surroundings, that is to say an aerial in a [illegible] which all the absorbing matter is at one temperature [illegible] the proper amount of noise for that temperature [illegible]

RR.286
15.7.45.
GRO.

Nyquist's formula (see Append. equation 8 and 9). The power in any band of frequencies will be proportional to bandwidth, and independent of frequency. An aerial exposed to cosmic noise does not follow this law. Although for small changes of frequency the power in any band is proportional to bandwidth, the noise power per unit bandwidth varies, being perhaps 4 times greater at 15 megacycles than at 30 mc/s.

In spite of the fact that the distribution of energy among frequencies does not follow Planck's formula (Append. equation 1) it is nevertheless convenient to specify the noise produced at the terminals of the aerial by means of an absolute temperature T_a, such that the available power is

$$k.\ T_a(f).\ df.\quad (k = \text{Boltzmann's constant})$$

where the temperature is written $T_a(f)$ to indicate that it will now depend on the frequency. The case of a directional aerial, exposed to a number of black bodies at different temperatures, is considered in the Appendix, and it is there shown that the effective temperature of the aerial is given by

$$T_a = \frac{1}{4\pi} \iint T(\theta,\phi).G(\theta,\phi).d\omega$$

where G is the gain of the aerial in any direction (θ,ϕ) and T is the "temperature of the sky" in that direction; a more precise definition of T is afforded by equation (3) of the Appendix. It may be noted that the subject resembles photometry in some respects, the wavelength however being much greater than that of visible light; and the value of T for any part of the sky may be regarded as analogous to its surface brightness.

A question which is commonly asked is, "If the intensity of the cosmic noise-radiation increases with increasing wavelength, does it not imply that the peak intensity occurs at a still longer wavelength and the absolute temperature, from Planck's formula, is very low indeed? Why then do we speak of temperatures of tens of thousands of degrees?" This argument fails to recognise that Planck's formula contains a single parameter only, namely the temperature, which determines the <u>absolute magnitude</u> of the intensity and not merely the manner in which it varies with wavelength. The absolute magnitude of the radiation from a black body at a very low temperature would be far too small.

The real reason for the increase of intensity with increasing wavelength is this: The interstellar matter, though very hot, is also very transparent. If it were completely transparent, the aerial array would only "see" the black sky beyond the interstellar gas. As it is, the aerial array picks up <u>dilute</u> black-body radiation. As we go to longer and longer wavelengths, the transparency of the gas diminishes and the radiation becomes rapidly less dilute, until finally the gas becomes quite opaque and we should received full black-body radiation. Before this limit is attained, however, ionospheric absorption sets in and complicates the picture.

Reber has calculated, following Kramers (1923) (Ref.12) that the apparent noise temperature varies roughly as λ^3, provided that the gas is not completely opaque, i.e. provided that the apparent temperature is well below the actual temperature of the gas.

CR. 286
13.7.45.
CED.

A general account of cosmic noise may be found in a report prepared for the Radio Research Board by H. A. Thomas and R. E. Burgess of the National Physical Laboratory (Ref. 1).

2. DISCUSSION OF THE AVAILABLE EXPERIMENTAL DATA:
(A) ANGULAR DISTRIBUTION OF NOISE SOURCES OVER THE SKY

Here the best information, and indeed the only detailed information, comes from Reber's experiments (Refs. 7, 8, and 9). Reber's results cannot be entirely accepted as he gives them, because he much overestimates the narrowness of the beam produced by his antenna system. From the dimensions of the mirror he used, it is evident that the beam widths must have been about 16° x 14° in the two principal planes, measured at half the central intensity. The apparent width of the Milky Way suggested by his data is to be ascribed mainly to the apparatus used, and the noise-producing region must be in fact mainly concentrated very close to the galactic equator.

This conclusion is confirmed by theoretical considerations. We must regard the interstellar gas as being sufficiently transparent for us to "see" on these wavelengths, (below about 15 metres) as far as the centre of the galactic system or very near it, in order to account for the variation of intensity with galactic longitude and the great increase in the Sagittarius region. If the interstellar gas were so opaque that a ray in the equatorial plane would only penetrate 1,000 parsecs * or so (a distance small compared with the dimensions of the galaxy), we should not expect to observe such an increase in Sagittarius as we do, as compared with Cygnus and the rest of the Milky Way. Now, the astronomical evidence indicates that the thickness of the sheet of interstellar gas is only a few hundred parsecs at most; and when seen from a distance of the order of 10,000 parsecs the angle it subtends will be quite small.

In practical applications (see Ref. 13) the calculations may be simplified by the assumption that the thickness of the noise source in galactic latitude is infinitesimal. While one obviously cannot expect this assumption to be strictly correct, the data available at present are not sufficient to warrant any more elaborate hypothesis. The reason for this is simply that no experimenter has hitherto used an antenna whose lobe is narrower than 15 degrees. And one may further deduce that the hypothesis of infinitesimal width will give satisfactory results in practical applications wherever the beams are more than 15 degrees wide, from the fact that experiments with such beams have been insufficient to disprove it.

It is proposed, therefore, to adopt for the time being the assumption that the noise comes from a line source running along the galactic equator. It is probable that in the next few years experiments will be conducted with larger aerial systems which may enable us to go beyond this simple working hypothesis.

There is no satisfactory evidence at present that the parts of the sky away from the Milky Way produce any noise whatever. And it would be expected on astrophysical grounds that the noise-intensity for the higher galactic latitudes would be very small indeed - as distinct from what happens in the case of ordinary starlight. (See Addendum, page 12, however.)

* A parsec is an astronomical unit of distance equal to 3.1×10^{13} kms (about 3.1 light years.)

CR 286
13.7.45.
CED

18

3. DISCUSSION OF THE AVAILABLE EXPERIMENTAL DATA:
(B) DATA ON THE ABSOLUTE INTENSITY

(a) Jansky's 1932 paper (Ref.2)

Jansky's original measurements are expressed in terms of the field strength of the equivalent plane waves which would produce the same signal strength as the noise. In order to reduce his results to equivalent noise temperature, it is necessary to know the gain of the aerial; it is no easy matter to calculate this for an aerial of the type he used, over imperfectly conducting ground.

The broadside array described in Jansky's 1932 paper may perhaps be regarded as picking up the energy flow over an effective area of $0.8\,\lambda^2$; the wavelength (λ) employed was 14.6 metres.

The energy flow along the direction of propagation of a plane wave is

$$\frac{cE^2}{4\pi} \times \left(\frac{10^9}{c^2}\right) \text{watts/square metre}$$

where E is the field strength in volts/metre, c is the velocity of light, 3×10^{10} cms./sec., and $10^9/c^2$ is the overall conversion factor required when employing the units given above.

The field strength reported by Jansky was about 23 db. below 1 microvolt/metre on the average, i.e. 0.07 microvolts/metre, for a bandwidth* of 1 kilocycle.

The power available at the aerial terminals would then be

$$0.8\,\lambda^2 \times \frac{cE^2}{4\pi} \times \left(\frac{10^9}{c^2}\right) \text{ watts/kilocycle bandwidth}$$

$$= 2.3 \times 10^{-15} \text{ watts/kilocycle bandwidth,}$$

which corresponds (see para.1) to a temperature of 170,000°K.

If this is a fair estimate of the mean effective temperature of Jansky's aerial, it may be taken as an indication of the mean effective temperature of the parts of the sky accessible to him, including the whole of the northern celestial hemisphere. It will be an unevenly weighted mean, but in any case it can only be a very rough estimate.

A general average is possibly misleading in so far as most of the noise comes from a small region (the Milky Way) which is much hotter than the mean, but it gives an idea of the noise temperature to be expected with a non-directional aerial. The maximum noise reported was very much greater (namely 0.39 microvolt metre^{-1} kilocycle$^{-\frac{1}{2}}$)* and corresponds to some 5,000,000°K.

These figures are much larger than those implied by his later work and must be regarded with suspicion. The discrepancy seems too great to be accounted for by uncertainties in the reduction of his field-strengths to temperature.**

---

* The noise power is proportional to bandwidth and the field strength therefore proportional to the square root of the bandwidth.

** Mr. Jansky has since informed the writer than he considers his later results should be used in preference to the results contained in his first paper. This adds support to the view which has been taken here.

C.P.286.
13.7.45.CED.

RESTRICTED

(b) Jansky's 1937 paper (Ref. 5)

In interpreting Jansky's later results it is interesting to calculate the noise factor of the receiver under the conditions in which it was used. The calibration of the system was effected by means of a signal generator presumably of the same impedance as the aerial. Using this method he gives the noise level as 47 db. below 1 micromicrowatt and hence the noise factor of the receiver is 4.9 db (or expressed as a ratio, 3.1)

To obtain the equivalent aerial temperature for an output corresponding to a power p from the signal generator, we equate the available powers from the (equal) impedances of aerial and signal generator:

$$kT_aB = p + kT_oB$$ (where B is the bandwidth and T_o the room temperature)

i.e.,
$$\frac{T_a}{T_o} = 1 + \frac{p}{kT_oB}$$

Inserting the value of kT_oB, namely 51.9 decibels below 1 micromicrowatt, it is now possible to translate all Jansky's 1937 figures into equivalent aerial temperatures.

Jansky's results have also been discussed by Thomas and Burgess; these authors are inclined to reject Jansky's figure of merit for his receiver as unreasonably good, but this would seem unjustified.

The wavelengths used by Jansky (16.7 metres and 14 metres) are rather long, and the incoming radiation must suffer considerable absorption in the ionosphere. The effect of this is clearly marked in the reduction of noise intensity during daylight which is a feature of the graphs of diurnal variation. A less obvious effect is the much larger amount of noise experienced with the horizontal dipole than with any other aerial system employed. This too seems to be due mainly to ionospheric absorption, for absorption is least at high angles and the horizontal doublet was the only aerial which was sensitive to high-angle radiation - from directions within 30° of the zenith, for example. Jansky himself remarks that both the maximum and the minimum noise levels obtained with the doublet exceed those measured with any of the other aerial systems.

The noise levels obtained by Jansky with the horizontal dipole correspond to about

$$T_a = 64,000^\circ \text{ at } \lambda = 16.7 \text{ metres}$$

on the average at night, rising to a maximum of over $100,000^\circ$. The values obtained with the other aerials are about a third as great, probably owing to absorption. It is important to note that this represents the average temperature of quite a large region of sky, only a small portion of which is occupied by the Milky Way - perhaps less than a quarter. The effective temperature of the Milky Way region is therefore greater, probably at least $300,000^\circ$ at this wavelength.

RESTRICTED

CR.286
13.7.45
GED

(c) Fränz's experiments (Ref. 6)

Fränz reports a test carried out in Germany at a wavelength of 10 metres. He used an aerial with a beam width of + 15° in azimuth, and a directivity in the vertical plane equivalent to that of two half-wave dipoles. According to his colleague Kleen (Ref. 14), the aerial was oriented so that its vertical plane of symmetry coincided once a day with the plane of the galaxy. (To see that this is possible it is only necessary to observe that in the latitude of Berlin there will be a time of day when the pole of the galaxy, which is in declination +28°, is rising or setting.) At this moment, the effective temperature of the aerial was 120,000°, and after allowing for the existence of side lobes in the aerial pattern and loss in the ionoshpere it seems that the "sky temperature" in the Milky Way region must have been not far short of 200,000° at this wavelength. Fränz's lowest figure namely 12,000° might be taken as an indication of the general mean temperature over the sky, but we should expect the latter to be rather higher than this; moreover it is again necessary to allow one or two db. for F-layer absorption, so that an average sky temperature of 20,000° should not be far wrong.

(d) Kinsey's experiments

The subject of aerial noise has been investigated by T.R.E. in connection with the performance of the radar warning Chain (A.M.E.S. Type 1, or CH.). Their conclusions are given in a report, 2/109 dated May 1941 (later reissued as T.R.E. Report T.1195 see Ref. 11.) It is unfortunately not possible to accept their results at face value, as it appears that all the absolute measurements of noise voltage are too high by some 10 or 15 db. *

The following reinterpretation of Kinsey's results is proposed tentatively. In Table III of his 6th para. he gives values of a constant η for different wavelengths. If we are right in interpreting these in terms of the modern noise factor N as approximately

$$\eta' = \frac{N - 2}{N - 1}$$

(and this is debatable), then we obtain the following values of the noise factor N

λ (metres)	6	7	10.3	13
N (decibels)	6.7	6.6	4.8	4.8

General experience with receivers indicates that these values, if not precise, at any rate cannot be far wrong. Turning next to his Table I (para.4), the absolute voltages are under suspicion, but the ratio μ can be used to derive the intensity of aerial noise. Introducing a factor exp (−β) to represent attenuation in the feeders we have

$$\left[\frac{T_a}{T_o} - 1\right] \cdot e^{-\beta} + 1 = \mu (N - 1)$$

* It may be mentioned that the values deduced for the scattering coefficient of aircraft are of nearly the right magnitude despite the incorrect noise figures, owing to another error of about the same magnitude which compensates the first one. This latter error consists in the omission of a crest factor in comparing observed signal/noise ratios with theory: actually, the apparent or mean-peak noise level is some 9 db above r.m.s. noise.

CD.286
13.7.45
CED

With the feeder losses quoted, this argument leads to the following effective temperature for the aerials :

λ (metres)	T (degrees K.)	T/λ^2
6	2,000	55
7	6,000	120
10.3	6,000	60
13	22,000	130

There is some indication of the noise temperature varying as the square of the wavelength.

It is unfortunate that one cannot use the absolute values of V_1 in the table, instead of μ. They show a remarkable degree of consistency in E_1, and therefore in T/λ^2. If Kinsey's absolute field strengths could be considered free from systematic error, they would lead to temperatures as follows:

λ	6	7	10.3	13
T	40,000	53,000	83,000	170,000
T/λ^2	1,100	1,100	800	1,000

These show a very regular variation with wavelength, but the absolute values are believed to be too high; otherwise the figure of merit of an RF7 receiver would have to be some 16 or 17 db. Moreover, we should expect a more rapid variation with λ than λ^2 on the currently accepted theory.

The author, who does not seem to have expected any diurnal periodicity, remarks that his figures are not very accurate because "over a long series of observations, the magnitude of the aerial noise on short waves was found to change by over a factor of 50%", which presumably means that the total range of variation was more than a factor of 2 in voltage.

(e) Fogg's experiments (Ref. 10)

According to unpublished experiments by Fogg at T.R.E. (Swanage) in December, 1941, aerial noise on 48-50 megacycles was approximately equal to set noise with a receiver using VR65 valves. The writer is indebted to Mr. Fogg for this information. This experiment was performed with a quarter-wave aerial, on a winter evening, and no variation with time was noticed in the course of a few hours. As the experiment was carried out at the least noisy time of the sidereal day, after the "hottest" part of the galaxy had set, this is not surprising. Taking the noise factor of the receiver as 7 db., the effective temperature of Fogg's aerial will have been about 1800°K.

RESTRICTED

(f) Reber's experiments.

Reber's experiments were conducted with a more sharply beamed aerial system than any other worker has used, the gain being about 150 and the beam width about $16^{\circ} \times 14^{\circ}$ measured at $\frac{1}{2}$ power. Because of the short wavelength employed (1.9 metres), the aerial noise was small compared with set noise, and even small compared with the resistance noise which a signal-generator would produce (Johnson noise). It had to be measured as a small residual difference, after balancing out the rectified noise from other sources.

As in the case of Jansky, it is fair to judge Reber's work on his most recent results, which are described in his 1942 paper (Ref. 9).

Accepting Reber's analysis of his apparatus as correct, except for the aerial system, it is easy to express his results in terms of aerial temperature. It follows from the equations in his 1942 Proc. I.R.E. paper that

$$T_a = \frac{\frac{1}{2}U}{kf_w} = 2T_f\Delta$$

where $2T_f = 2800$ degrees, and Δ is given by the fact that the percentages in the penultimate column of his Table III are equal to $100\,\Delta$. In this way we deduce temperatures of the order of 40° absolute, when the aerial is pointing at the galaxy; the highest value was 73°.

Reber has been criticised by Thomas and Burgess, on the ground that the sensitivity attributed to his receiver is impossibly good. Reference to his 1942 paper* will show that he regards the input impedance of his receiver as having an effective noise temperature of 1400°K. This implies a noise figure of 7.7 db., which is certainly lower than we should expect for a receiver using acorn valves. A more reasonable figure would be 14 db., and in view of the difficulty of matching his antenna to the receiver, the effective noise factor may have been considerably higher. This may account for the surprisingly low intensities, compared with those at higher wave lengths, although we should perhaps not insist too much on the [illegible] law. It seems probable that Reber's intensities are too small, but further experimental work in this region is obviously desirable.

We may reinterpret Reber's results taking into account the type of detector used and the re-estimated receiver noise factor. For a linear detector, his Δ, defined in eqn. (12) of the 1942 paper, is given by

$$\Delta = \frac{\sqrt{kT_af_w + (N-1)kT_of_w} - \sqrt{(N-1)kT_of_w}}{\sqrt{(N-1)kT_of_w}}$$

$$\frac{T_a}{2(N-1)T_o} \quad \text{where} \quad T_a \ll (N-1)T_o$$

(where N is the noise factor of the receiver)

---

* At his Note 7; and a sentence 10 lines above his equation (10).

CR.286
29/8/45
KM

RESTRICTED

which is Reber's eqn. (14) with substitution for the expression for N.

If the detector is square law,

$$\Delta = \frac{T_a}{(N-1)T_o}$$

It is possible that the detector was actually between the square law and linear ranges, making his temperature too high. On the other hand if we allow a noise factor of 14 db. we find from the above formula

$$T_a = 48\,T_o\Delta$$

as opposed to

$$T_a = 9.6\,T_o\Delta \quad \text{for } N = 7.7 \text{ db}$$

giving a probable increase of a factor of 5 in his calculated temperature. Allowing for the detector, we have possibly a factor of 4.

If this is true, the temperature of 40°K deduced from Reber's results with the aerial pointing at the galaxy should be about 160°K, and the maximum temperature of 73° should be about 360°.

Strictly speaking, these are temperature differences between the Milky Way and the dark sky well away from the galaxy; but it seems probable that the noise temperature of the sky elsewhere is a mere fraction of the temperature of the Milky Way.* Support for this view is afforded by Franz's data on 30 Mc/s.

Reber certainly underestimates the width of his beam, but this does not affect our conclusions appreciably.

---

* It should be noted that there exists a certain minimum value of the noise temperature of the aerial when pointing away from the Milky Way. This will be of the order of 10°K for the following reason.

If the aerial were transmitting, a certain fraction of the radiated power (about a third) would miss the mirror and impinge on the ground. This would be partially reflected, but an appreciable fraction (especially of the vertically polarised part, owing to the Brewster angle phenomenon) will be absorbed. Suppose for example that one tenth of the radiation would be absorbed in the ground. Since the ground is some 280° warmer than the extra-galactic sky, the effective noise temperature of the aerial will be raised 28 degrees above what it would be if the aerial could not "see" the surrounding ground.

This effect will have been balanced out along with the receiver noise, though it will reduce the calculated celestial temperature differences by 10%.

The drift due to changes of ground temperature at sunrise and sunset should be insignificant. The temperature of the mirror is, of course, immaterial.

GR.286
29/3/45
RM

In order to arrive at an estimate of the mean noise temperature for the whole sky, or for the northern celestial hemisphere, we may take an average round any parallel of declination, as they will give roughly the same result, with the exception of those near $\delta = 62^{\circ}$ (which touches the galactic equator) which will include too much of the Milky Way, and those above $\delta = 70^{\circ}$ which will include none of it. It can be shown that it is unnecessary to know the angular width of the beam or of the noise-producing part of the Milky Way: the width of the peaks on Reber's curves may be due to either, or to a combination of both, without affecting our result. In the samples he reproduces, the peaks are equivalent to a square peak of width about 1/30 of a revolution. Since there are two in each diurnal revolution, it is necessary to divide the mean peak temperature by 15. The result obtained is 3° K, or about 12° K with the higher noise factor.

This assumes that no noise is received when the aerial is pointing away from the Milky Way. There is no evidence against this in Reber's paper.

4. COMPARISON OF EXPERIMENTAL VALUES AT DIFFERENT FREQUENCIES

Owing to the uneven distribution of noise sources in the sky, the only figures which are strictly comparable are the mean temperatures for the whole sky. These are plotted in Figure 1. The maximum noise temperatures obtainable by pointing a beam antenna at the galaxy depend on the width of the beam, e.g. of the order of 5 times as great for a beam 30 degrees wide as for a non-directional antenna. No data exist to indicate by what factor the temperature may be reduced by pointing the aerial away from the galaxy. For all we know, the rest of the sky might be perfectly cold.

It is evident from Figure 1 that, if Reber's results are to be accepted, the noise temperatures vary roughly as λ^5. If we omit Reber's result, the remaining observations are best fitted by a variation as λ^3. In order to fit this law, Reber's noise figures would have to be too small by about 12 db., which is quite conceivable. It has been suggested above that Reber's own estimate of his noise figure is not intrinsically improbable, but considering all the evidence together it is difficult to resist the conclusion that the overall sensitivity of his system must have been less than he supposed.

Current theoretical ideas about the origin of cosmic noise indicate a variation as λ^2. It is argued that cosmic noise cannot originate in the stars, since the sun does not emit any* noise radiation, and that it must therefore come from interstellar matter. Working from Eddington's estimate of the constants involved, Reber obtained predicted noise intensities of the right order of magnitude. Amended calculations on interstellar matter have been made by Henyey and Keenan, but as they have published no particulars of their calculations it is difficult to know what importance should be assigned to their work. The results of Jansky and of Franz imply that the temperature of interstellar matter on these theories must be well above $100{,}000^{\circ}$, which does not fit in well with other astrophysical data. It is possible to produce arguments which lead to a variation as λ^2 rather than λ^3.

---

* It is now known that the sun does emit some noise radiation. See Addendum.

CR.2
29/8/45
KM

5 FINAL RESULT

We may adopt provisionally the following empirical formula for the variation of noise-intensity with wavelength

$$T \propto \lambda^3$$

To fix the absolute intensity, we may take the mean temperature of the whole sky to be 3000° K. at 6 metres (50 megacycles). For a non-directional aerial, there is diurnal variation in noise level of about 2 db.; for a highly directional aerial, the temperature may be 4 or 5 times as much when it is pointed at the galaxy. The radiation patterns of most aerials will show side and back radiation corresponding to a gain of the order of ½, and these side lobes will pick up radiation from the galaxy even when the aerial points in other directions; for this reason alone the aerial temperature can never fall very much lower than the mean figures quoted.

References:-

(1) H.A. Thomas and R.E. Burgess, (1943), D.S.I.R. Paper R.R.B/C90
(2) K.G. Jansky (1932), Proc. I.R.E. 20, p.1920 (Dec.)
(3) K.G. Jansky (1933), Proc. I.R.E. 21, p.1387 (Oct.)
(4) K.G. Jansky (1935), Proc. I.R.E. 23, p.1158 (Oct.)
(5) K.G. Jansky (1937), Proc. I.R.E. 25, p.1517 (Dec.)
(6) K. Franz (1939), Elektr. Nachr. Tech. 16, p.92
(7) G. Reber (1940), Proc. I.R.E. 28, p.68
(8) G. Reber (1940), Ap. J. 91, p.621
(9) G. Reber (1942), Proc. I.R.E. 30, p.367
(10) C.P. Fogg (1941), T.R.E., private communication
(11) B.B. Kinsey (1941), T.R.E. Report T.1195
(12) H. Kramers (1923) Phil. Mag. 46, p.836
(13) J.M.C. Scott (1945), R.R.D.E. Memo. No.88
(14) W. Kleen (1943), Elektrotech. ZS. 64, Heft 35/36, p.473

R.R.D.E.
Malvern, Worcs.
29.8.45.

CR.286
29/8/45
KM

RESTRICTED

ADDENDUM

(1) Since the preliminary version of this report, was circulated (Feb.1945) measurements have been made by K. F. Sander and J. G. Yates at R.R.D.E. at a wavelength of 5 metres. These measurements are the most accurate which have so far been made at a wavelength short enough to be little affected by ionospheric absorption. They correspond to a mean value of about 3,000 degrees K, so that our previous estimates were somewhat too low.

A further paper by Reber has appeared (Astrophys. Jnl. 100 (1944), p.279), which includes results obtained with a more stable receiver and plotted in a new way, but the remarks made above remain valid. His latest paper is, however, of great importance in that definite evidence is presented of noise coming from the sun. When the aerial was pointed at the sun, the signal was comparable with that obtained when pointed at the Milky Way. In considering the average over the whole sky, the Milky Way noise will nevertheless preponderate over the solar noise, because of the greater extent of the Milky Way.

Although solar noise is normally less important than cosmic (or galactic) noise, there is an occasion on record a few years ago when solar noise became very intense for a day or two. Between dawn and dusk it was sufficiently intense to reduce greatly the performance of 5-metre receivers, and was many times greater than ordinary cosmic noise. Details are given in a forthcoming A.O.R.G. Report (No.275).

(2) The writer is indebted to Mr. Sander and Mr. Yates for a discussion on Reber's receiver, and their views have been adopted in para. 3(f) of this report.

(3) The R.R.D.E. measurements have now been reported, in R.R.D.E. Research Report No. 285.

RESTRICTED

CR.286
13.7.45
CED

APPENDIX

The Effective Temperature of an Aerial

An aerial which is in thermal equilibrium with its surroundings, that is to say an aerial in a large enclosure in which all the absorbing matter is at one temperature, will generate the proper amount of noise for that temperature as given by Nyquist's formula. The power in any band of frequencies will be proportional to bandwidth, and independent of frequency. An aerial exposed to cosmic noise does not follow this law. Although for small changes of frequency the power in any band is proportional to bandwidth, the noise power per unit bandwidth varies, being perhaps 4 times greater at 15 megacycles than at 30 Mc/s.

Radiation in an Enclosure in Thermodynamic Equilibrium

In an empty enclosure with perfectly reflecting walls, the energy density of radiation (E_ν) in the range of frequencies ($\nu, \nu + d\nu$) is given by Planck's formula

$$E_\nu d\nu = \frac{8\pi h c^{-3} \nu^3 d\nu}{\exp(h\nu/kT) - 1} \qquad (1)$$

where c is velocity of light, h is Planck's constant, and k is Boltzmann's constant and T the absolute temperature.

It can be shown by purely thermodynamical arguments that E_ν must be of the form

$$E_\nu = \nu^3 . f\left(\frac{T}{\nu}\right)$$

(Wien's law). The correct form for the function $f(T/\nu)$ can only be obtained by quantum theory considerations. It is given incorrectly by classical theory as

$$E_\nu = 8\pi c^{-3} kT . \nu^2 \qquad (2)$$

(Rayleigh's formula) but this expression is nevertheless correct as an approximation to Planck's formula for high temperatures and long wavelengths. For purposes of radio and radar, it is correct as long as the temperature is more than a few degrees above absolute zero.

The enclosure need not be empty and may contain black or imperfectly black bodies at temperature T.

The radiation at a point may be analysed into sets of plane waves travelling in all directions. Those travelling in the directions which are contained within a small solid angle $d\omega$ possess energy which is a fraction $\frac{d\omega}{4\pi}$ of the total energy, $E df$, i.e. possess energy

$$2c^{-3} kTf^2 . df . d\omega \text{ ergs per cubic centimetre.}$$

(using f, now for frequency instead of ν). The power flow in the group of directions $d\omega$, is therefore

$$2c^{-2} kTf^2 df . d\omega \text{ ergs per second per square cm.} \qquad (3)$$

Application to Aerials

Now consider an aerial, say a narrow beam aerial, which only transmitts or receives one type of polarisation (say horizontal). Suppose it has a radiation resistance R and a gain $G(\theta,\phi)$ as compared with an isotropic source, in any direction (θ,ϕ). The function $G(\theta,\phi)$ specifies the radiation pattern of the aerial, drawn to the correct scale to indicate gains. Then from the definition of G,

$$\iint G(\theta,\phi)\,d\omega = 4\pi \tag{4}$$

In order to calculate the thermal noise received by the aerial it is necessary to consider what would be the ultimate fate of radiation transmitted by the aerial. Using optical language for the moment, suppose that an observer looking in the direction (θ,ϕ) from the aerial sees a black surface-element at temperature T; at any particular wavelength this has a surface-brightness which can be deduced from Planck's formula. If the surface which the transmitted radiation would strike first is only partially absorbing, then the value taken for T should be an appropriately weighted mean of the temperatures of the objects which would finally absorb the transmitted radiation.

The energy picked up by the aerial may now be calculated. It is easily shown that the power which the aerial is capable of transferring to a matched load i.e. the "available power", is

$$p = \frac{V^2}{4R} \tag{5}$$

where V is the r.m.s. voltage on open circuit and R the radiation resistance; p is also equal, in the case of plane waves, incident in direction θ,ϕ, to

$$\frac{\lambda^2 G(\theta,\phi)}{4\pi}\,W \tag{6}$$

where W is the power per unit area in the plane waves. Introducing a factor ½, since one kind of polarisation is not accepted by the aerial, it is found that the total power p in a frequency range $(f, f+df)$ is

$$\frac{kdf}{4\pi}\iint TG\,d\omega \tag{7}$$

If the whole of the surroundings of the aerial, or at any rate those which are relevant, are at the same temperature T, then (4) and (7) give

$$p = kTdf \tag{8}$$

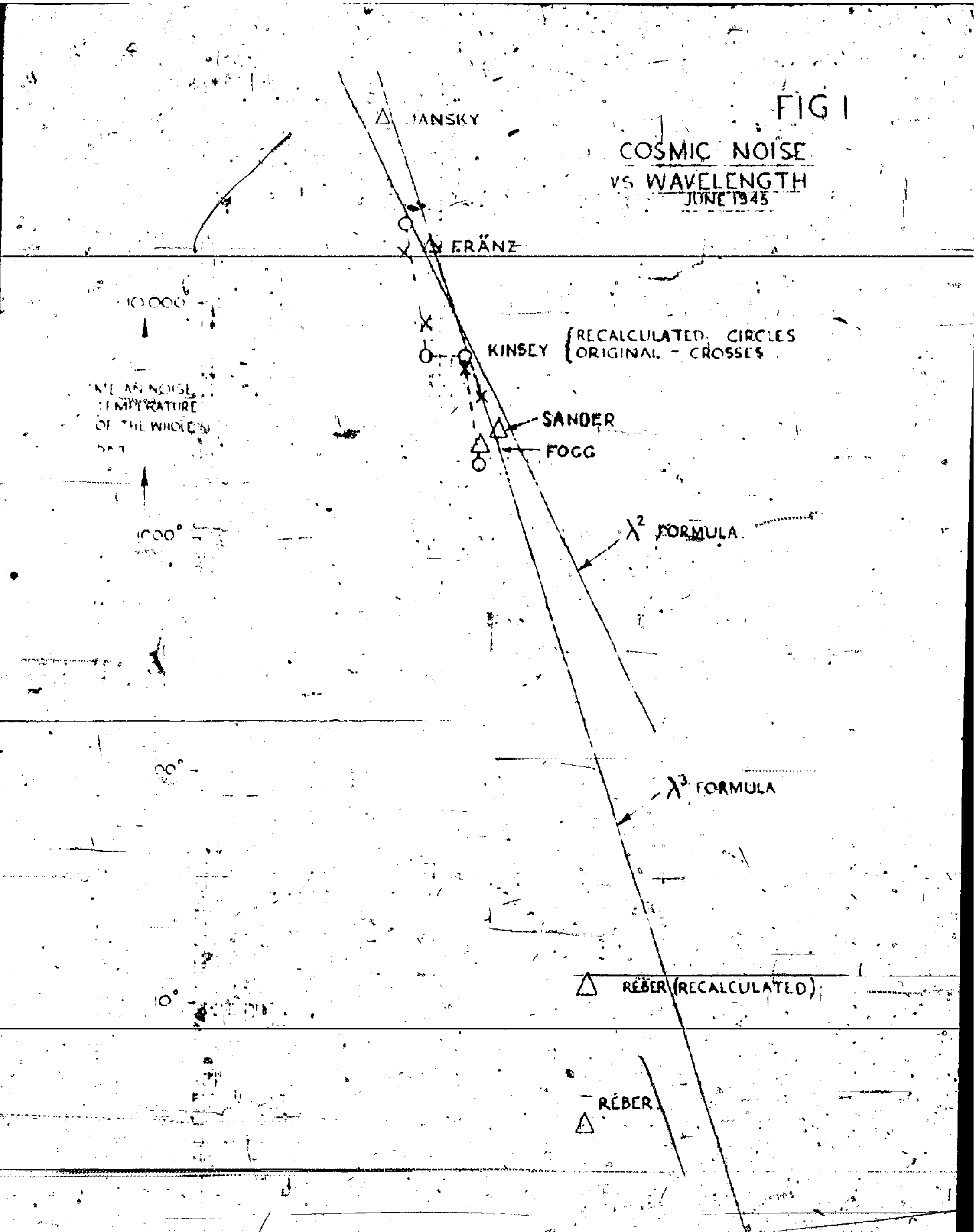
and, from (5),

$$V^2 = 4kTRdf \tag{9}$$

which is the well known formula of Nyquist.

If however the objects which would ultimately absorb the transmitted radiation are not all at the same temperature, it is nevertheless convenient to assign an "effective temperature" T_a to the aerial, which is a weighted mean of the true temperatures concerned. In other words the aerial can be treated as if it were an ordinary material resistor at a temperature

$$T_a = \frac{1}{4\pi}\iint T(\theta,\phi)\,G(\theta,\phi)\,d\omega \tag{10}$$



CR 286

RRDE R 7067/1/
DATED

CONFIDENTIAL

AD 139544

Armed Services Technical Information Agency

Reproduced by

DOCUMENT SERVICE CENTER

KNOTT BUILDING, DAYTON, 2, OHIO

FOR

MICRO-CARD

CONTROL ONLY

1 OF 1

CONFIDENTIAL

Received 2/8/00

DEPARTMENT OF DEFENSE
DIRECTORATE FOR FREEDOM OF INFORMATION AND SECURITY REVIEW
1155 DEFENSE PENTAGON
WASHINGTON, DC 20301-1155

12 JAN 2000

Ref: 98-M-0165/A1

[redacted]

This refers to our letter to you dated October 7, 1999, regarding your appeal to the Information Security Oversight Office for 14 documents previously requested under Mandatory Declassification Review procedures. One document (AD346727) was provided to you by our letter dated November 19, 1999.

The review of 11 British documents you requested is complete and there are no objections to release. Titles of these documents are contained on the enclosed sheet and a copy of each is enclosed. We will advise you as soon as the reviews of the remaining two documents are completed.

Sincerely,

SIGNED

H. J. McIntyre
Director

AD-036 799
AD-044 992
AD-048 643
AD-057 151
AD-057 524
AD-057525
AD-057 526
AD-057 527
AD-122 495
AD-136 830
AD-139 544

Per DoD letter,
Please mark these 11 documents "available to the public!"

I verified the docs could be marked available for public release via telecon with Pat Skinner, DoD Security Review, 695-7556/6428 on 11 Jan 2000.

Kelly Akers
DTIC RS

Received 2/8/2000